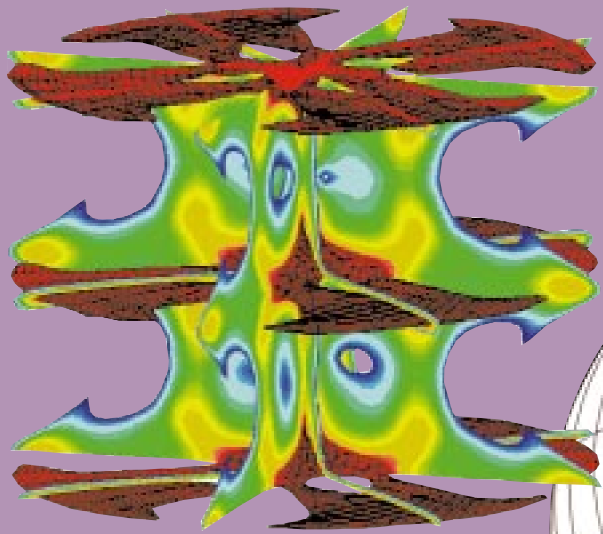
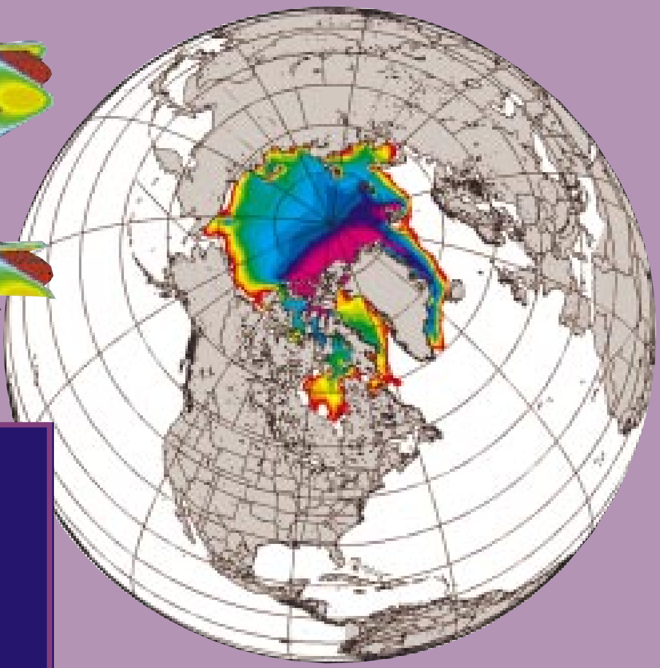
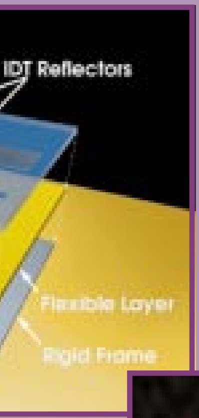
DoD HPC MODERNIZATION PROGRAM

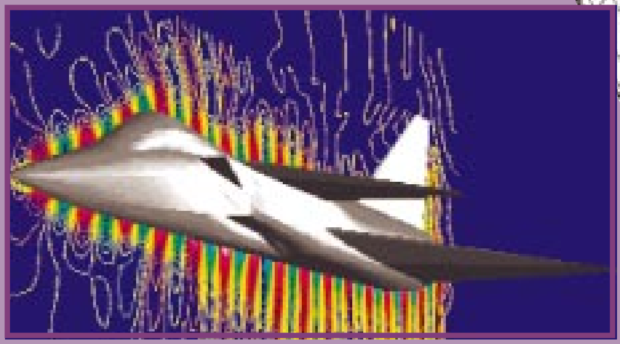
Department of Defense High Performance Computing

MODERNIZATION PLAN 1997









High Performance Computing

Supporting the Warfighter

Cover captions (left to right):

Top row –

Snapshot from a centroid molecular dynamics simulation of the proton transfer complex (blue and green) in water (red and white)

Cut planes and isosurfaces of mass density (in kg/m^3) of radially compressing plasma at 50 ns. The classical Rayleigh-Taylor spike and bubble pattern is easily recognized. The strong azimuthal variations are an indication of important 3-D physics.

Simulated Arctic ice thickness (meters) for June 30, 1992

Center row –

General configuration for picture-frame-mounted surface acoustic wave resonator

Parallel computation of scattered fields from a fighter for radar-cross-section prediction

Bottom –

Satellite image reconstruction: on-line compensation by adaptive optics, with postprocessing on the 400-node SP2 at the Maui High Performance Computing Center

contents

HIGH PERFORMANCE COMPUTING MODERNIZATION PLAN

March 1997

DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
3030 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-3030

This is the third edition of the Department of Defense High Performance Computing Modernization Plan. This plan has been prepared as required by Conference Report 104-863 which accompanied the Department of Defense Appropriation Act, Fiscal Year 1997.

We have made significant progress, since the last edition of this plan was published, towards our goal of improving the Defense Department's ability to exploit computation to provide the warfighter with the technological advantage. Five major contracts were successfully awarded to modernize the Department of Defense's high performance computing capability. Four of these contracts procure integration services which provide multiple large computer systems and expert support staffs at four major shared resource centers. The fifth contract provides high speed, high bandwidth network connectivity among users and the program's computing centers. Advised by user groups, the program is underwriting the development of application building blocks, visualization tools, system utilities, and mathematical libraries. In addition to these programmatic accomplishments, I am particularly encouraged at the collaborations across traditional service, institutional, and mission lines the program has engendered.

Sincerely,

Anita Jones

Anita K. Jones

EXECUTIVE SUMMARY

High Performance Computing (HPC) is a key enabling technology that is essential to maintain and extend the United States' technological advantage in warfighting systems. The HPC Modernization Program is the major force designed to improve the Department of Defense's (DoD) ability to exploit the computation necessary to sustain technological superiority on the battlefield. Managed by the Director, Defense Research and Engineering (DDR&E), the program is establishing a world-class, nationwide integrated infrastructure to support the defense research, development, test, and evaluation communities.

The HPC Modernization Program is creating HPC environments at shared resource centers that are accessible to local and remote scientists and engineers via a high-speed network. Advised by user groups, the program is underwriting the development of application building blocks, visualization tools, system utilities, and mathematical libraries. The adaptation of broadly based, widely used, scalable applications and algorithms to address growing science, technology, developmental test and evaluation requirements, along with continued training of users as new architectures and concepts evolve, is a vital part of the program. The program's four major shared resource centers are establishing collaborative partnerships with several civilian HPC centers in order to draw civilian expertise into the DoD.

Fiscal year 1996 saw the award of five major contracts to support the modernization of DoD's HPC capability. Four of these contracts will procure integration services to provide multiple large computer systems and expert support staffs at four major shared resource centers. The fifth contract will provide high speed, high bandwidth connectivity to the program's HPC centers. With an average annual budget of approximately $220 million, the program supports the research activities of more than 4200 scientists and engineers at nearly 100 defense laboratories, test centers, academic institutions, and industrial sites.

The successful award of the contracts is a major accomplishment for the HPC Modernization Program, but there is still much work ahead. While past efforts have been focused on acquisition activities, our efforts are now directed toward developing seamless computing environments across our centers. A robust suite of programming and developing tools, shared file systems, visualization capabilities, and interactive collaborative environments are needed to maximize the productivity of our most valuable resources—our scientists and engineers.

PROGRAM DESCRIPTION

Introduction

High performance computing (HPC) has played and will continue to play a major role in the ability of the United States to maintain and increase the technological superiority of its warfighting support systems. Very high fidelity modeling and simulation are the keys to rapid insertion of advanced technology into the design, test, and evaluation processes. The modernization of the Department of Defenses' (DoD) HPC capability will allow solutions to a wide variety of military-unique applications that require tremendous computing power.

Defense researchers are developing high-end applications that include calculating stealth aircraft signatures; modeling, at the molecular level, the flow of air or water across the surface of weapons systems; predicting sea lane weather; and simulating tests augmented with live testing. The use of HPC technology has already led to lower costs for system deployment, helped avoid damage to the environment, and improved the effectiveness of complex weapons systems. As DoD transitions its weapons systems design and test process to rely more heavily on modeling and simulation, the nation can expect many more examples of the profound effects that the HPC capability has on both military and civilian applications. Better use of computing technology is necessary to provide the United States with the military advantage required for operation in the 21st century.

Background

In 1991, Congress noted that DoD laboratories lagged behind the Department of Energy, National Aeronautics and Space Administration, and National Science Foundation supercomputer centers in HPC capability. Congress directed the DoD to establish a program to overcome this deficiency. This prompted the establishment of the DoD HPC Working Group, which developed the *HPC Modernization Plan* (delivered to Congress in May 1992). This group consisted of representatives from the military services, Defense Special Weapons Agency, Defense Advanced Research Projects Agency, and the Office of the Assistant Secretary of Defense for Command, Control, Communications, and Intelligence.[1] The DoD High Performance Computing Modernization Office (HPCMO) was subsequently established and staffed in fiscal year 1994 to ensure that the program supports the needs of the DoD science, technology, developmental test and evaluation programs. The achievements of the HPC Modernization Program are already visible in the success stories of our laboratories and test centers. The expectations for this program are that it will exert the force and the impetus needed by our scientists and engineers to provide new solutions to the problems of national defense within ever-constrained resources.

Vision and Goals

The High Performance Computing modernization vision is to enable the United States to maintain its technological supremacy over its adversaries in weapon systems design and to foster the flow of this technology into warfighting support systems.

Under the auspices of the Director, Defense Research and Engineering (DDR&E), the High Performance Computing Modernization Program is the major force that improves DoD's ability to exploit computation to sustain technological superiority. This effort will increase the DoD's HPC and communication capabilities to a level equal to or greater than those available in the foremost academic research centers and industry. The HPC Modernization Program involves creating HPC environments at four large centers and several smaller centers accessible to local and remote scientists and engineers via high-speed networks. The ability to provide for the adaptation of broadly based, widely used, scalable applications and algo-

[1] For a detailed description of these activities, refer to the *Department of Defense High Performance Computing Modernization Plan*, March 1992 and June 1994.

rithms to address growing science, technology, developmental test and evaluation requirements is an integral component of the program, along with continued training of users as new architectures and concepts evolve. The program pursues continuous interaction with the national HPC infrastructure, including academe, industry, and other government agencies to capture computing innovation and rapidly transfer it to the science, technology, developmental test and evaluation communities. The goals of the HPC Modernization Program are to:

- Buy the best commercially available high performance computers,
- Buy and develop software tools and programming environments,
- Expand and train the DoD user base,
- Link users and computer sites via high-speed networks (create collaborative work environments), and
- Exploit the best ideas, algorithms, and software tools of the national HPC infrastructure.

Management Strategies

Modernization of DoD's HPC capability and fulfillment of the programs' vision and goals requires a strategy that addresses all aspects of HPC. The programs' management strategies are:

(1) Goal—buy the best commercially available high performance computers.

- Provide a balanced set of commercially available heterogeneous computing environments for HPC systems to meet the full range of DoD requirements and to permit optimum mapping of requirements to system types.
- Build complete HPC environments, including large computing systems, at DoD laboratories and research developmental test and evaluation centers designated as major shared resource centers to support the community of users by providing large job service and establishing software environments and other support expertise.
- Place modest-sized high performance computational systems at selected, distributed centers, when that placement enriches the overall DoD capability for high performance computing.
- Support efforts designed to provide complementary HPC capabilities and technologies that are applicable to Defense science, technology, developmental test and evaluation requirements.

(2) Goal—buy and develop software tools and programming environments.

- Focus on standards in DoD research development test and evaluation software to ensure that future transitions and advancements in software technology are applied in an efficient and cost effective manner.
- Focus on applications-oriented software initiatives designed to overcome the technological inhibitors that delay the effective use of many scalable parallel high performance computers.
- Support software components used in specific computational areas or by a subset of users across the community.
- Identify software suites to be shared across selected major shared resource centers and distributed centers.

(3) Goal—expand and train the DoD HPC user base.

- Provide user education in computer and computational sciences, software applications and optimization, and code conversion.
- Promote the formation of DoD-sponsored interdisciplinary teams and collaboration groups to determine how best to support each computational area and to leverage academe and industry expertise in HPC for the solution of DoD problems.
- Develop shared-application area-specific software in support of high-priority and broadly needed computational application areas.
- Aggressively transfer expertise and knowledge among the user community. Expand the knowledge of the user community as applications require.

(4) Goal—link users and computer sites via high-speed networks (create collaborative work environments).

- Deploy robust and cost effective network connectivity consistent with HPC traffic requirements among and between DoD researchers and HPC assets and between the DoD and external research and development communities.

- Provide high-speed networking to connect users to a variety of centers, as required.
- Encourage remote usage
- Ensure that the highest priority applications are served.

(5) Goal—exploit the best ideas, algorithms, and software tools of the national HPC infrastructure.

- Ensure that DoD science, technology, developmental test and evaluation users remain cognizant of, interact with, and leverage internal DoD HPC initiatives, such as the Defense Advanced Research Projects Agency technology development efforts and the software development initiatives of the Defense research offices.
- Ensure that DoD science, technology, developmental test and evaluation users remain cognizant of, collaborate with, and leverage other Government agencies' and each other's HPC efforts.
- Maintain cooperative contact with the Computing, Information and Communication, Research and Development Subcommittee of the Federal High Performance Computing and Communications Program through the High End Computing and Communications Working Group.
- Provide HPC environments to support Defense applications that are directly related to dual-use technologies and National Challenges, e.g., environment, medical, automotive, and manufacturing processes and products.
- Ensure the availability of HPC environments to support Defense applications that address DoD Challenge Projects needs, e.g., meteorological, oceanographic, and environmental modeling; nature of new materials; structure of biological and chemical phenomena; and energy efficient vehicles and airplanes.
- Leverage the nation's HPC infrastructure to benefit Defense research and development.

Scope

The HPC Modernization Program provides and sustains high-end high performance computing resources for defense science, technology, developmental test and evaluation programs.[2] The communities supported by this program have been defined by the Congress to include:

> *". . . capability at (1) the DoD Science and Technology sites under the cognizance of the Director, Defense Research and Engineering, (2) the DoD Test and Evaluation centers under the Director, Test and Evaluation (Office of the Under Secretary of Defense, Acquisition and Technology), and (3) the Ballistic Missile Defense Organization . . ."*

(Public Law 104-61, December 1, 1995, 109 Statute 665, Sec. 8073).

By limiting the program's scope to HPC systems and focusing the majority of computational resources at a few consolidated shared resource centers, the program is able to acquire and operate high-end resources that cannot easily be obtained by individual services or agencies. The definition of "high performance" changes with the evolution of technology. The program's mission statement is specifically written to follow technological improvements, effectively transitioning to more powerful systems as previous levels of capability become affordable at the laboratory or project level.

Computational Technology Areas

The HPC Modernization Program user base includes over 4000 scientists and engineers at 100 defense laboratories, test centers, universities, and industry sites across the nation. Users within the program have organized themselves into 10 computational technology areas. Table 1 lists the 10 Computational Technology Areas and their descriptions. Each computional technology area has a designated leader who is a prominent DoD scientist or engineer working within the scientific domain of the computional technology area. Each computional technology area leader chairs a working group comprised of scientists and engineers from each of the services, with participation by Defense agencies as appropriate. These computational technology area working groups serve as focused user groups to drive program investment strategies for hardware, software, and support services decisions. Table 2 lists the computional technology areas and the leaders.

In addition to being an effective tool for directing major facilities investments, organizing around the

[2] The HPC Modernization Program identifies science, technology, developmental test and evaluation as functional areas in which the program provides support to all encompassing HPC requirements.

Table 1 - Computational Technology Area Descriptions

Computational Structural Mechanics covers the high-resolution multidimensional modeling of materials and structures subjected to a range of loading conditions including static, dynamic, and impulsive loads. Example applications for this area include structural analysis, structural acoustics, ship response to underwater explosion, and weapon system lethality/survivability.	**Computational Chemistry and Materials Science** focuses on the basic properties of new chemical species and materials that may be difficult or impossible to obtain experimentally, such as molecular geometry, inter-molecular forces, reaction energies, and mechanical properties. Applications include new rocket propellants and better materials for weapons systems.
Computational Fluid Dynamics, the accurate numerical solution of the equations describing fluid and gas motion, finds its primary use in the analysis and engineering design of complex systems. Specific applications include studies of submarine maneuverability in shallow water, the dynamic response of military stores during launch, the redesign of aircraft tail components to reduce fatigue, and simulations for improved fire/explosion safety and destruction of obsolete munitions.	**Environmental Quality Modeling and Simulation** focuses on the solution of coupled, multidimensional equations for surface, overland, and subsurface hydrodynamics and transport, plus the response thereto of biotic species. Applications for this area include assessment of ecosystem impacts from DoD activities, cleanup of environmental impacts resulting from past DoD practices, and establishment of effective management of natural and cultural resources under DoD stewardship.
Integrated Modeling and Test Environments uses simulation techniques in conjunction with live-fire tests, hardware-in-the-loop testing, and evaluations. Applications include real-time trajectory calculations, digital scene generation, and the simulation of weapon system components in a virtual operations context.	**Forces Modeling and Simulation** covers the use of command, control, communications, computer, and intelligence for battle space management, complex engagement training, and real-time decision-making support. Areas of potential impact for DoD include precision strike planning and force-level simulations.
Computational Electromagnetics and Acoustics investigates the high-resolution multidimensional solution to the equations of electromagnetics and acoustic wave propagation in different media. Applications include antenna array design, electromagnetic and acoustic signature identification, surveillance and communication enhancement, countermine measures, and optimizing stealth aircraft.	**Computational Electronics and Nanoelectronics** involves network and field theory, linear/nonlinear analysis, synthesis and formal design methods to model and simulate complex electronic devices, integrated circuits, and systems of devices. Areas impacted by these codes include device synthesis, optimization of high-frequency sensors and processors, design of tomorrow's faster computers, and advanced communications.
Climate/Weather/Ocean Modeling and Simulation uses numerical computation to model the Earth's climate, oceanic variability, and atmospheric changes. Numerical simulations provide strategic weather forecasting and long-term climatological prediction.	**Signal/Image Processing** includes the extraction of useful information from sensor output in real time. DoD applications in areas of surveillance, communication, and electronic warfare include the development of advanced radars, sonars, and image-processing systems.

computational technology areas also provides an effective template for assessing both the importance and the opportunities of HPC to sustain U.S. warfighting technical superiority. For example, the degree of linkage between the activities of the HPC Modernization Program user community and warfighting objectives can be demonstrated by cross-referencing the computational technology areas to the specific warfighting priorities—the Joint Warfighting Capability Objectives determined by the Joint Chiefs of Staff. Table 3 shows the correlation between Joint Warfighting Objectives and work under way in each of the computational technology areas.

User Requirements

One of the most critical program activities has been the constant dialog with the defense science, technology, developmental test and evaluation user communities. A vigorous requirements analysis process has been implemented, which includes annual validation of requirements to provide accurate, timely data upon which to base program decisions. The requirements analysis process includes an extensive program of surveys sent to every user and every known potential user, coupled with visits to selected DoD HPC user sites to discuss requirements with and provide program information to individual user groups. In addition to the formal requirements-gathering process, the program also obtains feedback through user satisfaction surveys, annual user group meetings, and a users advisory council that works with a site managers council to establish operational policies and procedures at the program centers.

Table 2 - Computational Technology Areas and Leaders
from 1996 Requirements Analysis

Computational Technology Area	Leader and Location	E-mail Address
Computational Structural Mechanics (CSM)	Kent Kimsey, Army Research Laboratory	kimsey@arl.mil
Computational Fluid Dynamics (CFD)	Jay Boris, Naval Research Laboratory	boris@lcp.nrl.navy.mil
Computational Chemistry and Materials Science (CCM)	Scott Wierschke, Phillips Laboratory	wierscsg@quantum.ple.af.mil
Computational Electromagnetics and Acoustics (CEA)	Joe Shang, Wright Laboratory	shang@fim.wpafb.af.mil
Climate/Weather/Ocean Modeling and Simulation (CWO)	Joe McCaffrey, Naval Research Laboratory – Stennis Space Center	mccaffrey@nrlssc.navy.mil
Signal/Image Processing (SIP)	Richard Linderman, Rome Laboratory	lindermanr@rl.af.mil
Forces Modeling and Simulation (FMS)/C^4I	Bob Wasilausky, Naval Command, Control and Ocean Surveillance Center, Research Developmental Test and Evaluation Division	wasilaus@nosc.mil
Environmental Quality Modeling and Simulation (EQM)	Jeff Holland, U.S. Army Corps of Engineers Waterways Experiment Station	hollanj@exl.wes.army.mil
Computational Electronics and Nanoelectronics (CEN)	Barry Perlman, Army Research Laboratory – Fort Monmouth	bperlman@ftmon.arl.mil
Integrated Modeling and Test Environments (IMT)	Andrew Mark, Army Research Laboratory	amark@arl.mil

Table 3 - Correspondence Between Joint Warfighting Capability Objectives
and HPC Modernization Program Computational Technology Areas

Joint Warfighting Objectives	Computational Technology Areas									
	CSM	CFD	CCM	CEA	CWO	SIP	FMS	EQM	CEN	IMT
Information Superiority				●	●	●	●			●
Precision Force	●		●	●		●	●			
Combat Identification				●		●				
Joint Theater Missile Defense	●	●	●	●	●	●	●		●	●
Military Operations in Urban Terrain		●	●	●	●	●	●		●	●
Joint Readiness				●		●	●			
Joint Countermine	●	●	●	●	●	●	●	●		
Electronic Warfare				●		●				
Information Warfare				●		●	●			
Chemical/Biological Agent Detection		●	●	●	●	●	●	●		
Real-Time Logistics Control						●	●			
Counter-Proliferation	●	●	●		●	●	●	●		●

Figure 1 shows the HPC requirement for a few key DoD problems. In addition to the problems identified in the figure, increasing fidelity will be required for newly emerging HPC applications, such as model-driven test and evaluation and high-fidelity forces modeling and simulation. Other important hardware requirements, such as on-line file storage, archival data, and network bandwidth will require increases in capabilities to support growing requirements.

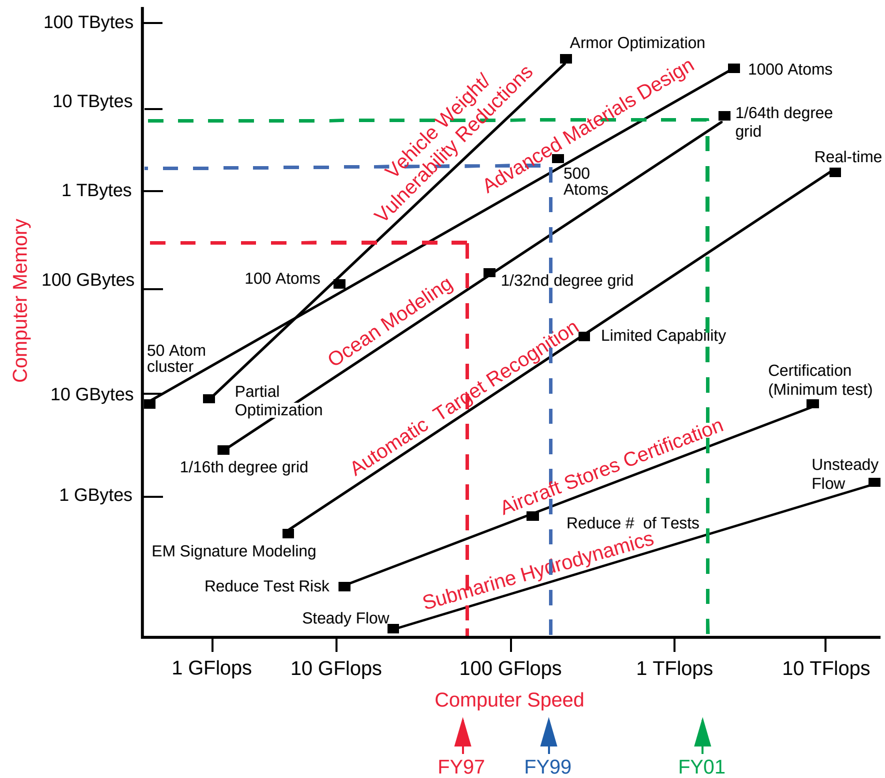


Fig. 1 - Requirements for key DoD problems

The overall conclusion of this requirements analysis is that a complete HPC environment must be provided to take full advantage of HPC capabilities within the DoD research, development test and evaluation program as it supports development of defense warfighting systems. This environment requires a broadly accessible infrastructure that includes (a) a variety of well-balanced high-end computational platforms; (b) a full complement of systems and applications software by scientists and engineers in each of the 10 computational technology areas; (c) software tools that facilitate the transition of much of the DoD computational workload to scalable systems; (d) a reliable high-speed network that links the computational scientists, engineers, and analysts at their user sites with the computational resources located at the HPC Modernization Program's shared resource centers; (e) an aggressive training program that continues the education and expansion of the DoD HPC user base to accelerate the exploitation of HPC capabilities. Progress must be balanced across all program activities to optimize the impact of the HPC Modernization Program on the DoD research, development test and evaluation program in its support of the defense warfighting mission.

Program Initiatives

The DoD modernization effort is a multifaceted process consisting of a phased acquisition plan for HPC centers, coupled with the appropriate level of computational software development and wide-area network support. The program has three initiatives: HPC centers, which consist of major shared resource centers and distributed centers, networking, and software support.

High Performance Computing Centers

Major Shared Resource Centers

To most effectively and efficiently use the full range of HPC assets, the HPC Modernization Program provides for the establishment and sustainment of four large major shared resource centers that have a wide range of HPC capabilities and are designed to support the broad DoD laboratory and developmental test and evaluation communities. Each of the program's major shared resource centers has been designated to support specific computional technology areas. Each center's hardware and software configurations, programming environments, and training efforts are focused to support the needs of the designated computional technology areas for that center. They include various types of computing systems, scientific visualization capabilities, peripheral and archival storage, as well as providing the expertise in the use of these assets. These large centers provide DoD HPC users with stable hardware and software, with an emphasis on supporting large computational requirements/problems. Software includes programming tools focused on specific computational technology areas for each center. The unique features at each major shared resource center are the programming environment and training component. This effort, in addition to extensive training on a wide variety of user needs, will also provide system tools to facilitate the effective and efficient use of the HPC systems. This will be accomplished through the collaborative partnerships the major shared resource centers have established with several leading civilian HPC centers in order to draw needed civilian expertise into DoD. Table 4 lists the four major shared resource centers.

Distributed Centers

Distributed centers provide HPC capability to a specified local and remote portion of the HPC Modernization Program user community. Modest-sized HPC systems are deployed to distributed centers where there is a significant advantage to having a local HPC system and where there is a potential for advancing DoD applications using investments in the HPC capabilities and resources. Distributed centers are deployed to leverage specific HPC expertise or to address problems that cannot be solved at the major shared resource centers, such as real-time data processing, signal image processing, and embedded systems applications. Table 5 shows the current distributed centers and their locations. In addition to the distributed centers in

Table 4 - Major Shared Resource Centers

Center	Location
Aeronautical Systems Center (ASC)	Wright-Patterson Air Force Base, Ohio
Army Corps of Engineers Waterways Experiment Station (CEWES)	Vicksburg, Mississippi
Army Research Laboratory (ARL)	Aberdeen Proving Ground, Maryland
Naval Oceanographic Office (NAVO)	Stennis Space Center, Mississippi

Table 5 - Distributed Centers
(as of March 1997)

Center	Location
Air Force Development Test Center (AFDTC)	Eglin Air Force Base, Florida
Arnold Engineering Development Center (AEDC)*	Arnold Air Force Base, Tennessee
Army High Performance Computing Research Center (AHPCRC)	University of Minnesota, Minnesota
Maui High Performance Computing Center (MHPCC)	Kihei, Hawaii
Naval Air Warfare Center (NAWC)*	Patuxent River, Maryland
Naval Command, Control and Ocean Surveillance Center (NCCOSC)	San Diego, California
Naval Research Laboratory (NRL)*	Washington, District of Columbia
Naval Undersea Warfare Center (NUWC)	Newport, Rhode Island
Redstone Technical Test Center (RTTC)**	Huntsville, Alabama
Rome Laboratory (RL)	Rome, New York
Space and Strategic Defense Command (SSDC)	Huntsville, Alabama
Tank-Automotive Research Development and Engineering Center (TARDEC)	Warren, Michigan
White Sands Missile Range (WSMR)*	White Sands Missile Range, New Mexico

*Distributed centers funded for upgrades for fiscal year 1997.
**An additional distributed center for fiscal year 1997.

Table 5, the Arctic Region Supercomputer Center has been funded by Congress in fiscal years 1996 and 1997 and is providing computational resources to the HPC Modernization Program user community. The Arctic Region Supercomputer Center is not formally designated as a distributed center because it lacks a DoD sponsor. The distributed centers are linked by medium- to high-speed communications to the major shared resource centers and remote users. Thus, they augment the major shared resource centers to form the total DoD HPC capability.

Networking

A robust, high-speed network is essential to ensure that the program's HPC capabilities can be effectively used by a large, geographically dispersed user community. Approximately 1000 of the 4000 HPC Modernization Program users reside at the four major shared resource centers, making the majority remote users.

The Defense Research and Engineering Network (DREN) will provide the connectivity to link the HPC Modernization Program users to the program's shared resource centers to each other and to other HPC-supporting national networks. DREN is an expandable set of network services that can be accessed upon demand. DREN uses a public communications grid; networking capability is specified as a given level of service at each site, with no definition of interconnecting pathways (as portrayed in Fig. 2). Service levels at each site may be adjusted as networking requirements change. Adding and deleting sites from the network and increasing service levels can be easily accomplished.

The DREN Intersite Service contract will provide wide-area connectivity initially at up to 155 megabits per second with upgrade potential to 2.4 gigabits per second. Service levels offered by the contract will support the growing networking requirements. Larger problem sizes, remote interactive visualization of computations, interactive collaborations, and heterogeneous computing across systems at several provider sites will drive the demand for much greater network bandwidth.

The networking initiative is supported by the Defense Information Systems Agency and the Defense Advanced Research Projects Agency and includes the Defense Simulation Internet requirements. Currently an interim networking capability (see Fig. 3), which merged the Army Supercomputer Network and the Air Force Supercomputer Network with selected Navy sites and the Defense Special Weapons Agency network hubs, supports access to existing resources through T-3 (45 megabits per second) backbone and T-1 (1.5 megabits per second) tail circuits. This interim network is being phased out as new network services become available under the DREN Intersite Services Contract.

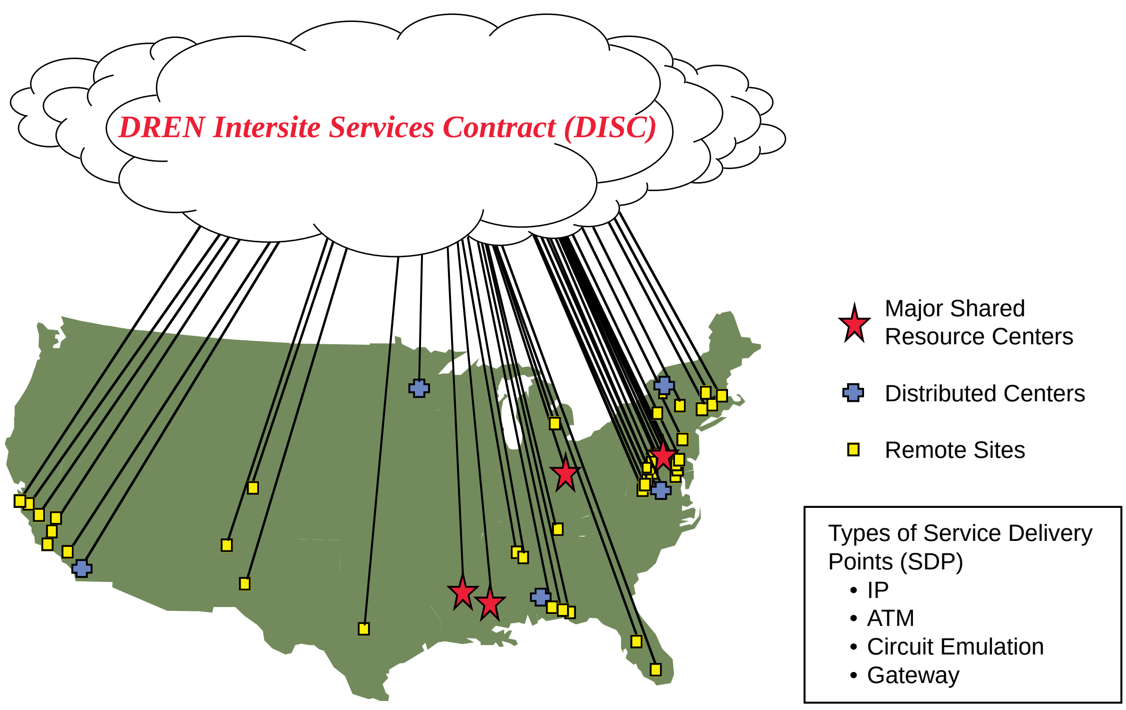


Fig. 2 - DREN Intersite Services Contract - Connectivity "Cloud"

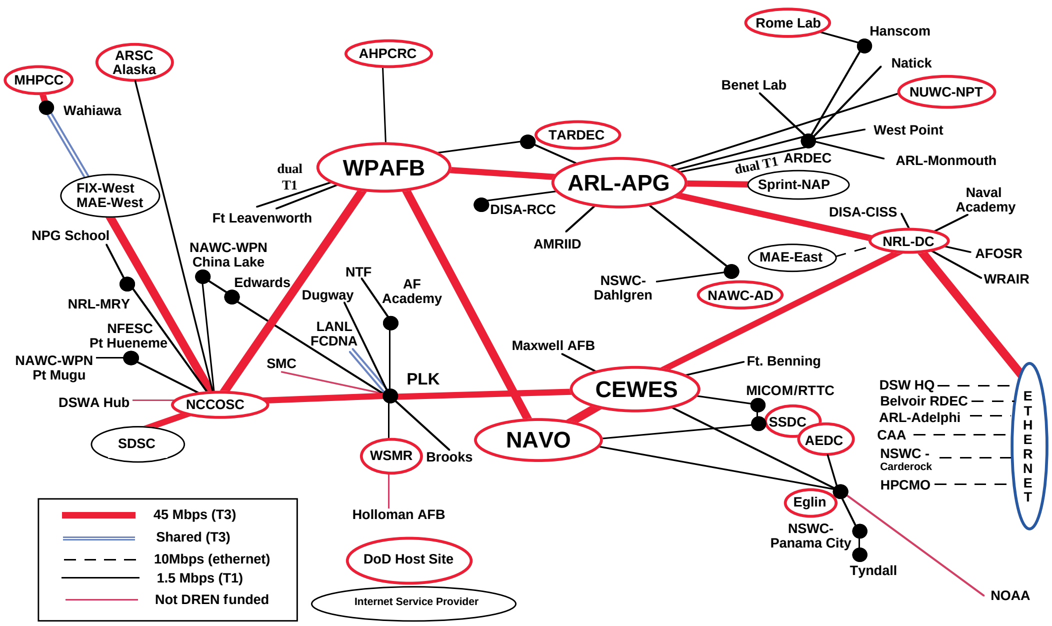


Fig. 3 - The Interim Network—point-to-point connectivity

Software Support

The Common HPC Software Support Initiative (CHSSI) is an applications software development effort designed to provide DoD computational scientists and engineers with applications software tools essential to exploit high end, scalable HPC systems. Scalable parallel hardware provides price/performance advantages over traditional serial vector hardware and offers greater memory sizes, which allow larger problems to be solved. Defense-specific scalable applications software is essential to realize the advantages of scalable parallel systems.

This initiative leverages the expertise of the DoD scientists and engineers and allows them to work as specialized teams to resolve common software needs. The initiative encourages cooperation and collaboration, not only among DoD computational scientists, but also among scientists in other Federal departments, industry, and academia. The CHSSI products will be a suite of multipurpose codes that run efficiently on the new generation of high-end systems. These products will facilitate a large fraction of the computational workload in support of DoD warfighting requirements. This initiative provides the requisite underlying software to support the development of defense applications capable of exploiting the vast potential of scalable systems.

The goals for the CHSSI are to develop critical DoD software applications that can execute in a scalable computing environment and foster reuse of software tools and application components, appropriate use of communication interface, and graphics visualization standards across DoD. Further, the CHSSI goals are to promote the development of new software tools and application area specific software and to leverage HPC expertise and assets located in industry, academia, and other federal laboratories in addition to DoD facilities.

The Common HPC Software Support Initiative is organized around the 10 computational technology areas. The applications software projects were determined by the Computational Technology Area working groups. Table 6 lists the projects and the principle investigator in each computational technology area.

The software support initiatives will provide personnel funding to develop applications for DoD laboratories and test centers within the programming environments available at the major shared resource centers. The software development involves multilaboratory and interservice teams drawn from their respective computational technology area working groups. These teams will be responsible for development, dissemination and technology transfer and be made up of algorithm and code developers, applications specialists, and end users. The teams may include partners from academia, industry, and other government agencies. The CHSSI will provide support for approximately 40 projects over the next 5 years. Academic partnerships are encouraged to exploit sabbatical, visiting-scientist, post-doctoral, and graduate student arrangements. They may include other government agency and commercial partners. Teams may employ conventional support contractor arrangements provided there are no proprietary restrictions on resulting software or capabilities. Although all of these team arrangements are possible, the overriding purpose of the initiative is to enhance and create expert groups within DoD that span laboratories, organizations, and services.

Table 6 - Computational Technology Areas, Projects, and Principal Investigators

Computational Technology Areas	Project	Principal Investigator	E-mail Address
Computational Structural Mechanics	Small Deformation Structural Mechanics Large Deformation Structural Dynamics Scalable Algorithms for Shock Physics Structure-Medium Interaction Model	Gordon Everstine Raju Namburu Kent Kimsey Mark Emery	geversti@oasys.dt.navy.mil namburr@exl.wes.army.mil kimsey@arl.mil emery@lcp.nrl.navy.mil
Computational Fluid Dynamics	FAST3D - Global Virtual-Cell Embedding Gridding COBALT - Unstructured Gridding FEFLO - Unstructured Gridding OVERSET - Chimera Gridding MERCURY - Block Structured Gridding ARL Zonal Navier Stokes - Block Structured Gridding	Jay Boris Bill Strang Ravi Ramamurti Robert Meakin Steve Scherr Roger Strawn	boris@lcp.nrl.navy.mil strang@fim.wpafb.af.mil ravi@lcp.nrl.navy.mil meakin@nas.nasa.gov scherr@fim.wpafb.af.mil strawn@merlin.arc.nasa.gov
Computational Chemistry and Materials Science	Car-Parinello Methods for Solids Quantum Chemistry Tight-Binding Molecular Dynamics Classical Molecular Dynamics	D.J. Singh Jerry Boatz D.A. Papaconstantopoulos Ruth Pachter	singh@witan.mbvlab.wpafb.af.mil jerry@helium.ple.af.mil papacon@dave.nrl.navy.mil pachterr@ml.wpafb.af.mil
Computational Electromagnetics and Acoustics	Automatic Target Recognition and Scene Generation Code Electromagnetic Interaction Code Spectral Domain Low Observable Component Design Code Synthetic Sensor Code for Fusion Time Domain Code High Resolution Computational Electromagetics and Acoustics Code Magnetohydrodynamic Code	Jeff Hughes Jay Rockway Kueichien Hill Russ Burleson Helen Wang Miguel Visbal Robert Peterkin	jah@witan.mbvlab.wpafb.af.mil rockaway@nosc.mil hillkc@sga254.wpafb.af.mil rburleso@mbvlab.wpafb.af.mil helen_wang@mlngw.chinalake.navy.mil visbal@fim.wpafb.af.mil bob@ppws07.plk.af.mil
Climate/Weather/ Ocean Modeling and Simulation	Ocean Models with Domain Decomposition Scalable Global Weather Forecast System Global and Regional Wind Wave Modeling	Steve Piacsek Tom Rosmond Robert Jensen	piacsek@nrlssc.navy.mil rosmond@nrlmry.navy.mil jensen@madmax.cerc.wes.army.mil
Signal/Image Processing	Radar Sonar Synthetic Aperture Radar/Image Formation Processor Automatic Target Recognition Infrared/Optical Image Processing	Rich Linderman Bob Bemecky Christopher Yerkes David Gadd Lynda Graceffo	lindermanr@rl.af.mil bernecky@starbase.nl.nuwc.navy.mil yerkes@nosc.mil dgadd@mbvlab.wpafb.af.mil graceffo@nvl.army.mil
Forces Modeling and Simulation/ C^{4}I	Scalable HPC Environment for Command, Control, Communications, Computers, and Intelligence Simulation Leveraged Acquisition Test and Evaluation Efficient Parallel Discrete Event Simulation for Analysis HPC Frameworks for Warming and Training Simulations	Guy Leonard Henry Ng Bill Smith Larry Peterson	gleonard@nosc.mil hng@relay.nswc.navy.mil smith@ait.nrl.navy.mil ljp@nosc.mil
Environmental Quality Modeling and Simulation	Structured-Unstructured Modeling Scalable Multi-Dimensional Contaminant Transport and Fate Modeling for Surface Water and Surface Water/Groundwater Interactions Scalable Parallel Implementation of DoD Groundwater Modeling System	Robert Bernard Mark Dortch Fred Tracy	bernard@hl.wes.army.mil dortchm@exl.wes.army.mil tracy@exl.wes.army.mil
Computational Electronics and Nanoelectronics	Microwave Circuit Simulation Power Semiconductor Simulation Parallel Very High Speed Integrated Circuit Hardware Description Language Simulation Electromagnetic Solvers	Dave Rhodes Robert Pastore John Hines Leo DiDomenico	rhodes@arl.mil pastore@doim6.monmouth.army.mil hines@el.wpafb.af.mil ldidomenico@arl.mil
Integrated Modeling and Test Environments	Real-time Synthetic Test Environment Representation High Fidelity Physics Based Models for Testing Simulation Based Design and Test Technology	Harry Heckathorn Joel Mozer Andrew Mark	harry@vader.nrl.navy.mil mozer@plh.af.mil amark@arl.mil

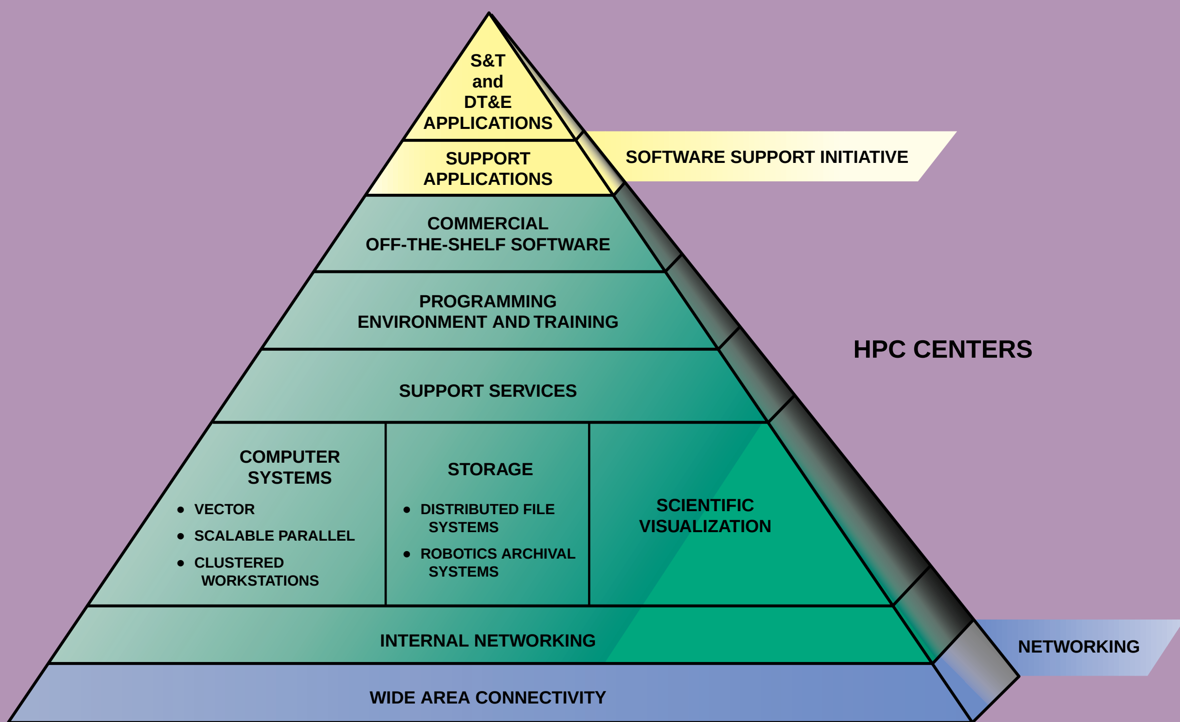


Fig. 4 - DoD HPC Modernization Program - Integrated Program Strategy

The HPC Modernization Program is establishing a world-class, nationwide, integrated infrastructure to support the HPC needs of the defense science, technology, developmental test and evaluation communities. As depicted in Fig. 4, the program has an integrated strategy to provide complete computing environments to increase DoD scientists' and engineers' productivity. Connecting the program's HPC centers and users is a high-speed, high-bandwidth network. The major shared resource centers operate the large HPC systems available to the entire HPC Modernization Program community. Each major shared resource center provides a full range of resources, including hardware, software, data storage, archiving, visualization, training, and expertise in specific computational technology area. The distributed centers supplement the major shared resource centers to form the total HPC Modernization Program's computing capability. These centers typically have smaller high performance computers to develop and test particular high end applications. Software support is an important program element. Advised by user groups, the program is underwriting the development of application building blocks, visualization tools, system utilities, and mathematical libraries. The combination of the software support effort with the HPC centers, networked together with users, will constitute a state-of-the-practice capability with which our scientists and engineers will routinely conduct world-class reseach, development, test, and evaluation.

PROGRAM ACCOMPLISHMENTS

The HPC Modernization Program made significant progress over the past 2 year towards its goal of modernizing DoD's HPC capability. Concurrent acquisitions to provision the four major shared resource centers and provide robust, wide-area networking were initialized, announced, and executed. Contracts for the Major Shared Resource Centers acquisitions were successfully awarded, as shown in Table 7. The DREN Intersite Service Contract was awarded to AT&T in July 1996.

The program selected and began funding the common application software development projects to ensure that an efficient, robust set of applications building blocks will be available to support a broad base of the RDT&E computational workload. Processes for user input regarding requirements, upon which the program is based, were expanded. To ensure that important computationally intensive DoD problems receive the necessary program resources, new allocation policies were initiated. An outcome of these new allocation policies was the selection of a set of DoD "Challenge" projects, which will receive approximately 20% of the program's computing cycles. These projects will result in significantly improved models to address important DoD problems such as determination of blast damage on structures for counterproliferation and counter-terrorism scenarios, disposal of expired munitions, mine warfare in littoral waters, and finer calculation of stealth signatures to improve invisibility across the electromagnetic spectrum.

The integration contracts awarded for the four major shared resource centers will provide for hardware, software, maintenance, operations, and expert support staffs. Built into the major shared resource centers multiyear contracts is the option of upgrading to higher capability as technology and resources become available. Each of the contracts includes a base computational capability, Performance Level I, and two options for upgrades, referred to as Performance Levels II and III. Table 8 shows the initial systems populating the centers and their aggregate peak

Table 7 - Major Shared Resource Center Contract Award Dates

Organization	Location	Contractor	Award Date
Army Corps of Engineers Waterways Experiment Station	Vicksburg, Mississippi	Nichols Research Corporation	March 1996
Air Force Aeronautical Systems Center	Wright-Patterson Air Force Base, Ohio	Nichols Research Corporation	May 1996
Naval Oceanographic Office	Stennis Space Center, Mississippi	Grumman Data Systems	May 1996
Army Research Laboratory	Aberdeen Proving Ground, Maryland	Raytheon E-Systems	August 1996

Table 8 - Major Shared Resource Center Performance Level 1 Capability

Center	HPC Systems	Total Site Capability (Peak gigaflops)
Army Corps of Engineers Waterways Experiment Station	Cray Y-MP,* Cray C90,* Cray T3E, SGI PCA, SGI Origin	191
Naval Oceanographic Office	Cray 90,* Cray T90, SGI PCA(2), Cray J932SE	51
Army Research Laboratory	SGI PCA,* SGI Origin (3), Cray J932 (2), Cray T90(2)	88
Aeronautical Systems Center	Intel Paragon,* Cray C90, IBM SP, SGI PCA	73

* HPC systems installed prior to the 1996 integration contract awards

computational performance. In most cases, all systems are now present and operational at the centers.

One of the key features of the major shared resource centers contracts is the programming environment and training effort. Each integrator has established collaborative partnerships with several civilian HPC centers as a mechanism for rapidly capturing innovation and bringing needed expertise in HPC into DoD. Organized around the program's 10 computational technology areas, this effort will focus on training the DoD user base, identifying HPC technological opportunities, and introducing these opportunities into the program's shared resource centers' computing environments.

Augmenting the computing capabilities at the major shared resource centers, the HPC Modernization Program established seven new distributed centers and upgraded existing systems at four distributed centers over the 3-year period of fiscal years 1995 through 1997. These distributed centers will apply HPC to a variety of DoD problems including real-time data analysis, man-in-the-loop and hardware-in-the-loop testing and evaluation, and development of specific HPC applications. Table 9 shows the centers which were selected for new or upgraded systems for fiscal years 1995 through 1997.

Tables 10 and 11 show the program's total HPC capability as of March 1997. As a result of the major shared resource centers contract awards and the fiscal years 1995 and 1996 distributed centers implementations, total peak capability increased from 239 gigaflops in fiscal year 1994 to over 983 gigaflops as of January 1997. Additional capability will be available in fiscal years 1997 and 1998, as the program executes the Performance Level II upgrades at the major shared resource centers and completes the fiscal years 1997 and 1998 distributed centers' new acquisitions/enhancements.

Connecting the centers will be the Defense Research and Engineering Network, for which a contract was awarded to AT&T. With approximately 75% of the program's user base located at sites other than the major shared resource centers, a robust wide area network is essential to ensuring that our scientists and engineers can make efficient use of the program's HPC capabilities. The DREN is a virtual private network and will replace the interim DREN, which has been operational since 1993. Initial bandwidth will vary from 10 megabits per second to 155 megabits per second (OC3), with upgrade potential of 2.4 gigabytes per second (OC48) over the 5-year life of the contract. Ten sites are scheduled to be implemented by the spring 1997 and the entire 60 government sites by the end of 1997. In addition to government sites, DREN will provide gateways to many existing military and civilian networks. Contractor and university facilities not at government locations will link with the program's centers via these gateways.

Funding for the CHSSI projects began in March 1996. This effort will provide a suite of multipurpose codes that will perform on a range of HPC platforms with attention to portability to other systems, both present and future. Approximately 40 projects in 9 computational technology areas were selected by the computational technology leaders. The projects will be developed by teams chosen by the computational

Table 9 - Distributed Centers for Fiscal Years 1995 through 1997

Center	Location
Air Force Development Test Center (AFDTC)	Eglin Air Force Base, Florida
Arnold Engineering Development Center (AEDC)	Arnold Air Force Base, Tennessee
Army High Performance Computing Research Center (AHPCRC)	University of Minnesota, Minnesota
Maui High Performance Computing Center (MHPCC)	Kihei, Hawaii
Naval Air Warfare Center (NAWC)	Patuxent River, Maryland
Naval Research Laboratory (NRL)	Washington, District of Columbia
Naval Undersea Warfare Center (NUWC)	Newport, Rhode Island
Redstone Technical Test Center (RTTC)	Huntsville, Alabama
Space and Strategic Defense Command (SSDC)	Huntsville, Alabama
Tank-Automotive Research Development and Engineering Center (TARDEC)	Warren, Michigan
White Sands Missile Range (WSMR)	White Sands Missile Range, New Mexico

Table 10 - DoD HPC Modernization Program Computational Resources at the Major Shared Resource Centers

Performance Level 1 Final (as of March 1997)

Location	DoD HPCMP System	Number of Processors	Total Memory (gigabytes)	Disk Storage (gigabytes)	Total Capability (Peak gigaflops)
Aeronautical Systems Center	Intel Paragon	368	11	115	26
	Cray C90	16	8	202	16
	IBM SP	80	68	990	25
	SGI PowerChallenge	16	8	202	6
	Total Site Capability (gigaflops)				73
Army Corps of Engineers Waterways Experiment Station	Cray C90	16	8	228	16
	Cray Y-MP	8	1	115	3
	Cray T3E	256	33	370	154
	SGI PowerChallenge	32	16	202	12
	SGI Origin 2000	16	8	196	6
	Total Site Capability (gigaflops)				191
Army Research Laboratory	SGI PowerChallenge	96	16	232	29
	SGI Origin 2000	32	12	206	13
	Cray T90	4	4	480	7
	SGI Origin 2000 (Secret)	32	12	206	13
	Cray T90 (Secret)	4	4	240	7
	Cray J932 (Special Access)	16	8	252	3
	Cray J932 (Special Access)	16	8	252	3
	SGI Origin 2000 (Special Access)	32	12	412	13
	Total Site Capability (gigaflops)				88
Naval Oceanographic Office	Cray C90	16	8	330	16
	Cray T90	6	4	224	11
	SGI PowerChallenge	36	12	212	13
	Cray J932SE (Classified)	12	4	224	2
	SGI PowerChallenge (Classified)	24	8	210	9
	Total Site Capability (gigaflops)				51
	Total Major Shared Resource Centers Capability (gigaflops)				403

technology area leaders. The teams are drawn from the respective computational technology area working groups and include partners from academia, industry, and other government agencies. Additional projects in the Integrated Modeling and Test Environments computational technology area are planned for initiation in the 2nd quarter of fiscal year 1997.

The HPC Modernization Program held a CHSSI public information meeting in March 1996, to announce the common HPC software support initiative projects. This meeting provided an opportunity to discuss plans for the effort and to encourage interactions with academia, industry, and other government agencies. A CHSSI Workshop was held in June 1996 for the CHSSI development teams at which programming standards' guidelines and performance metrics for the projects were presented.

Advised by the program's user advocacy group (Shared Resource Centers Advisory Panel) and the service/defense agencies executives' representatives to the program's HPC Advisory Panel, the HPC Modernization Office established a resource allocation policy to effectively distribute the program's computing resources. The new policy, scheduled to be fully implemented in fiscal year 1998, has two parts: allocation of a specified portion of the program's total

Table 11 - DoD HPC Modernization Program Computational Resources at the Distributed Centers (DCs)

(as of March 1997)

Location	DoD HPCMP System	Number of Processors	Total Memory (gigabytes)	Disk Storage (gigabytes)	Total Capability (Peak gigaflops)
Air Force Development Test Center	Cray T3D SGI Onyx	128 32	8 8	140 40	19 12
Army High Performance Computing Research Center	TMC CM-5	896	29	116	115
Arnold Engineering Development Center	Convex C4640 Convex C4640 (Classified) Convex C3880 Convex Exemplar SPP-2000	4 4 8 32	2 2 2 4	100 100 40 50	3 3 2 13
Maui High Performance Computing Center	IBM SP IBM SP (Classified) IBM SP/SMP	400 80 115	64 8 15	822 227 553	106 21 39
Naval Air Warfare Center	SGI PowerChallenge	40	12	300	15
Naval Command, Control and Ocean Surveillance Center	Intel Paragon (Classified) Convex Exemplar SPP-1000	336 32	14 8	128 160	25 6
Naval Research Laboratory	TMC CM-500e TMC CM-500e Convex Exemplar SPP-2000 SGI Origin 2000	256 32 64 64	33 4 16 16	400 50 150 85	41 5 46 25
Naval Undersea Warfare Center	Cray T3D	64	4	76	10
Rome Laboratory	Intel Paragon	321	21	80	30
Tank-Automotive Research, Development and Engineering Center	SGI PowerChallenge	64	16	385	24
White Sands Missile Range	TMC CM-500	128	16	96	20
				Total Distributed Centers Capability (gigaflops)	580
				Total HPC Modernization Program Capability (gigaflops)	983

computing resources to support very large, computationally intensive problems and allocation of the remaining computing cycles to the remaining set of service/agency requirements projects, with 30% each for the Army, Navy, and Air Force and the remaining 10% for other DoD agencies. Each service then distributes its share according to its needs.

The allocation of computing resources to support large, computationally intensive problems resulted in the selection of a set of projects for fiscal year 1997, referred to as DoD Challenge Projects. These projects were selected via a competitive process by a selection board that included reviewers from outside of DoD. Selection was based on DoD priority requirements, scientific merit, and potential for progress. These projects will receive approximately 20% of the computing cycles available at the major shared resource centers and selected distributed centers. The initial set of DoD Challenge Projects are summarized in Table 12. Allocations averaging 6 gigaflop years per project

Table 12 - Fiscal Year 1997 DoD Challenge Projects

Project	Organization	Primary CTA	HPC System(s)
1/16th Degree Global Ocean Model	Naval Research Laboratory	CWO	Cray T3E
A First Principles Computation of the Process of Deflagration-to-Detonation Transition	Naval Research Laboratory	CFD	TMC CM-5
Airborne Laser Challenge Project	Phillips Laboratory	CEA	Cray T3E IBM SP
Analysis of Jet Interaction Phenomena for the Theater High Altitude Area Defense Interceptor	Program Executive Office - Air Missile Defense	CFD	Cray C90
Automatic Aerodynamic Design for Complete Aircraft Configurations	Air Force Office of Scientific Research	CFD	Cray T3E
B-1B Radar Cross Section Prediction	Wright Laboratory	CEA	Cray T90 SGI PCA SGI Origin
Design of New Materials Using Computational Chemistry	Air Force Office of Scientific Research and Phillips Laboratory	CCM	IBM SP
Impacts of Subsurface Heterogeneity on Military Site Cleanup	Army Corps of Engineers Waterways Experiment Station	EQM	TMC CM-5
Khobar Towers Bomb Damage and Water Tamping Studies	Army Corps of Engineers Waterways Experiment Station	CSM	Cray T3E
Modeling of Complex Projectile-Target Interactions	Army Research Laboratory	CSM	Cray-2 Cray T90 SGI PCA
Near Real-Time Multispectral Sensor Simulation Using Parallel Ray-Tracing	Army Research Laboratory	IMT	SGI PCA
Open-Air Detonation of Expired Munitions	Naval Research Laboratory	CFD	IBM SP SGI PCA Exemplar
Parallel Simulations of Flow-Structure Interactions	Office of Naval Research	CFD	Cray T3E IBM SP
Simulation of Explosions for Counter-Proliferation and Counter-Terrorism Scenarios	Defense Special Weapons Agency	EQM	SGI PCA Cray C90 Cray T3E
Time-Domain Computational Ship Hydrodynamics	Office of Naval Research	CFD	IBM SP SGI PCA TMC CM-5 Cray C90
Towards the Virtual Prototyping of Radio Frequency Weapons	Phillips Laboratory	CEA	IBM SP Cray C90

were made for the January-September 1997 time period. A yearly competition for DoD Challenge Projects is planned.

The 1995 and 1996 annual DoD HPC Users Group Meetings were held. The 1995 meeting was sponsored by and hosted at the Naval Research Laboratory Distributed Center in Washington, D.C.; the 1996 meeting was sponsored by the Aeronautical Systems Center' Major Shared Resource Center and hosted by the National Center for Supercomputing Applications (NCSA) in Urbana-Champaigne, Illinois. Both meetings, with over 100 attendees, provided information on the HPC Modernization Program initiatives and offered a forum for interaction among the program's center management staffs, program office staff, and users. The 1996 Users Group Meeting, held at NCSA, also provided an opportunity for the program's shared resource centers' staffs and users to interact with NCSA staff.

The HPC Modernization Program is a major automated information system program and, as such, must meet all Major Automated Information Systems Review Council (MAISRC) life-cycle management milestone requirements. In April 1994, the HPC Modernization Office received Milestone 0 approval to initiate the program, and Milestone 1 was granted in February 1995. The Major Automated Information Systems Review Council conducted a formal Milestone 2 review of the HPC Modernization Program in December 1995. The Milestone Decision Authority (MDA) issued the System Decision Memorandum on 4 January 1996. This milestone approval allowed substantial progress toward meeting the program's goals. In the subsequent months, the program awarded contracts for four major shared resource centers, six distributed centers, and wide-area-networking services and released funds to support the Common HPC Software Support Initiative projects.

The Program Office has established several focused Integrated Product Teams (IPTs) and continues to work through the IPT process to accomplish its goals. During 1996, 11 IPT sessions were held. The sessions resolved testing, cost, and security issues. The last IPT session was an approval, senior-level Working IPT (WIPT). The program submitted the Single Acquisition Management Plan, with appropriate attachments, and requested approval to execute planned fiscal year 1997 implementations for the Common HPC Software Support Initiative and the fiscal years 1997 and 1998 distributed centers. The Common HPC Software Support Initiative implementations and the fiscal year 1997 distributed centers were subsequently approved.

HPC CONTRIBUTIONS TO MISSION SUCCESS

High performance computing enables detailed computer-based design, virtual prototyping, and improved numerical modeling in order to significantly shorten the acquisition cycle and reduce the costs of weapons system procurement. High-end computational capabilities impact all aspects of DoD research, development, test, and engineering—from basic research in the laboratories to testing and evaluating at the test centers. The extent of this impact is accelerating. Computational modeling and simulation allow the exploration of more options, at a fraction of the cost, than with traditional theoretical and experimental methods. The use of high performance computing, coupled with judiciously chosen experimental data points, provides a powerful tool for improving the development process of DoD warfighting and support systems.

Although the DoD HPC Modernization Program has fielded HPC capabilities for approximately 3 years, a number of major accomplishments have already resulted from the use of high-end computing in the DoD science and technology program. In 1995 and 1996, the HPC Modernization Program published *Contributions to DoD Mission Success From High Performance Computing*. This section highlights a few of the most notable successes from the 1996 edition. The accomplishments were selected based on scientific content and application to the DoD mission. The 12 success stories highlighted here are contributed from the Army, the Air Force, the Navy, and the Defense Special Weapons Agency. The stories span 8 of the 10 DoD computational technology areas and include work performed using several of the new, scalable HPC systems. The accomplishments presented show the crucial role that high-end computing plays in a variety of defense application areas:

- Ship Structural Response to Underwater Explosions - CSM
- Glass Window Design to Mitigate Terrorist Threat - CSM
- C-17 Paratrooper Operation - CFD
- SADARM Submunition Collision Solution - CFD
- Elimination of Explosives and Propellants Through Environmentally Safe Open-Air Detonations - CFD
- Conducting and Semiconducting Polymers by Design - CCM
- Determination of Blast Damage on Structures - CSM/CFD
- Advanced Warfighting Concepts Using Plasmas - CEA
- Cofired Ceramic Package for a Ka-Band MMIC Phase Shifter - CEN
- Embedded High Performance Computing for real-time Target Detection and Tracking - SIP
- Global Ocean Modeling - CWO
- Pollutant Cleanup Strategies within DoD - EQM

Additional applications software projects are being developed for use on new, scalable high-end systems under the DoD HPC Modernization Program's software support initiative.

Ship Structural Response to Underwater Explosions

The Navy's need for a modernized minehunting platform, for use in potential Persian Gulf-like conflicts, necessitated a quick assessment of a new platform's resistance to underwater explosions. The urgency for the procurement resulted in the decision to forego a costly and time-consuming experimental assessment program. The system had to be assessed independent of traditional "design-build-test" experimental techniques. HPC technology was identified as the only available means by which the technical requirements could be met within the time frame and allowed budget. The needed level of detail required the development of new models for two main equipment rooms. (See Fig. 5.) As a result of the successful implementation of this shock assessment using HPC systems, the Navy identified a number of critical design deficiencies. The Navy's analysis persuaded the shipbuilder to acknowledge these deficiencies and to accept responsibility for them. The use of high-end computing was a major step toward assuring that the design of the coastal minehunter system met the requirements for shock-hardening. In the process of implementing this HPC solution, the Navy has gained insight into the behavior of complex composite structures subjected to underwater explosions.

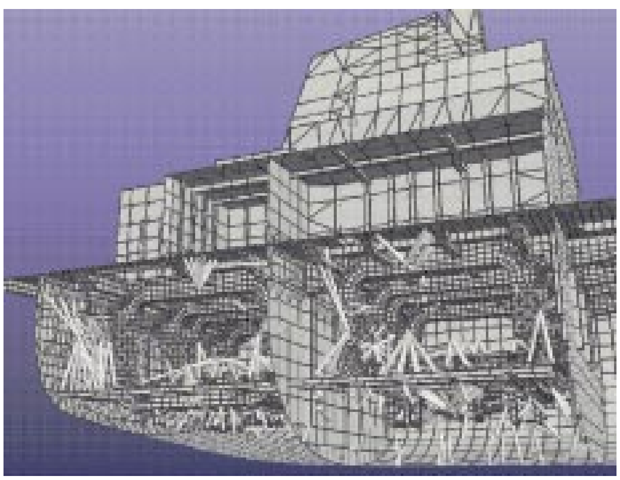


Fig. 5 - Cutaway view of finite-element model of equipment rooms

Glass Window Design to Mitigate Terrorist Threat

Because of recent terrorist attacks, both at home and abroad, assessment of the vulnerability of existing government buildings to blast loadings has become a mission priority. One important aspect of this assessment is the prediction of the lethality of glass fragments to human occupants. Injury to humans due to glass fragments has been demonstrated to be dependent on fragment size and velocity. Average fragment size can be determined experimentally, but fragment velocities due to blast loadings are difficult to measure. To quickly assess the effects of charge weights and standoff distances to variations of glass thickness and strength, a matrix of finite element analyses was created using HPC systems. Glass variables included window size, single or double-pane thickness, and strength. Results from the analyses were used to develop equations for predicting the velocity of glass particles based on window size, thickness, strength, and blast characteristics. (See Fig. 6.) These results can be used to evaluate the threat to building occupants from glass fragments due to terrorist's bombs and to determine the best methods of retrofitting existing buildings to diminish the human risk from flying glass fragments.

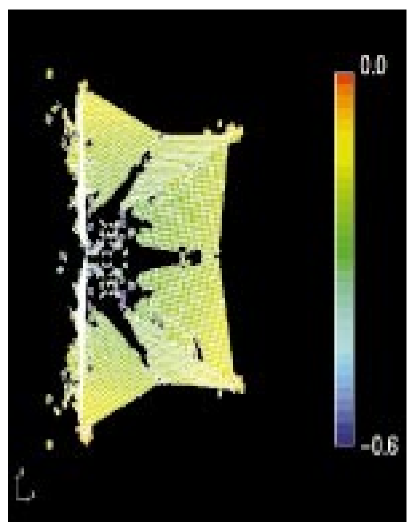


Fig. 6 - Bending failure of single-pane glass window under blast loading

C-17 Paratrooper Operation

The C-17 aircraft was designed to accommodate a mass exit of 102 fully equipped paratroopers. In August 1994, during routine development flight testing of mass paratrooper operations, a pair of Army jumpers encountered a high-altitude parachute entanglement (both jumpers landed safely). The Army and Air Force immediately began work to understand and resolve the phenomenon that caused this type of encounter. This phenomenon is not unique to the C-17. To understand the phenomenon and develop a solution that would allow the C-17 to satisfy operational requirements, both the Army and Air Force formed a joint Executive Independent Review Team. Using both the DoD and the National Aeronautics and Space Administration HPC resources, the Air Force developed computational fluid dynamics simulations to provide insight for the Executive Independent Review Team on the salient features of the C-17 and C-141 flowfields. The Executive Independent Review Team subsequently oversaw water tunnel and wind tunnel tests to confirm the best operational configuration and to satisfy Army requirements. The final configuration was verified in April 1995 when over 300 jumpers, spanning three sorties, safely exited a C-17 at the Army's Yuma Proving Ground, Arizona. Figure 7 shows streamlines behind the C-17 aircraft predicted by computational simulation for typical speeds and configurations of paratrooper exit.

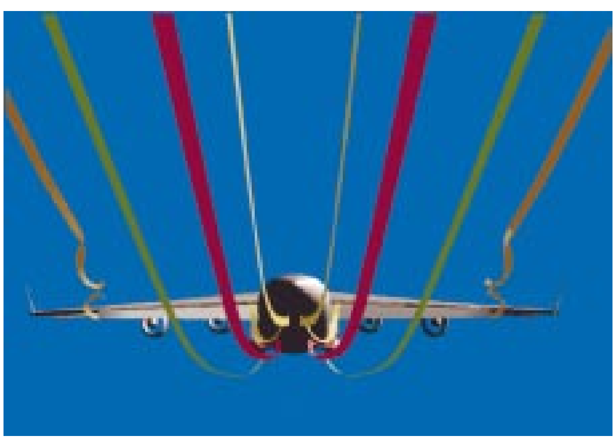


Fig. 7 - Streamlines behind aircraft at typical speed and configuration for paratrooper exit

SADARM Submunition Collision Solution

The Sense and Destroy Armor (SADARM) system is an artillery-delivered (155 mm), tank-killing system with sensors designed to find and direct penetrators to the relatively "soft" top of armored vehicles. During the development cycle of this program, problems were experienced with in-flight collisions that damaged and rendered useless the expelled submunitions. Through the use of DoD HPC assets and an advanced multibody computational fluid dynamics capability, the underlying physics, which led to the submunition collisions, was modeled and understood. The computed results for the original design, shown in Fig. 8, indicate regions of low speed flow (blue) and high-speed flow (red-yellow). The distribution of the variations in flow around the paired munitions effectively drew them together. A new design with drag fins was developed and tested by HPC simulation. This result was subsequently verified by a less costly test schedule made possible by the simulation. This success helped reverse a pending decision by the Defense Acquisition Board to discontinue the system. Instead, low rate production was approved for SADARM. The accomplishment resulted in savings of time and dollars. Most significantly, this breakthrough in 3-D, time-dependent computational fluid dynamic methodology suggests the need for and value of engaging the services of HPC modeling in the early phases of the development cycle.

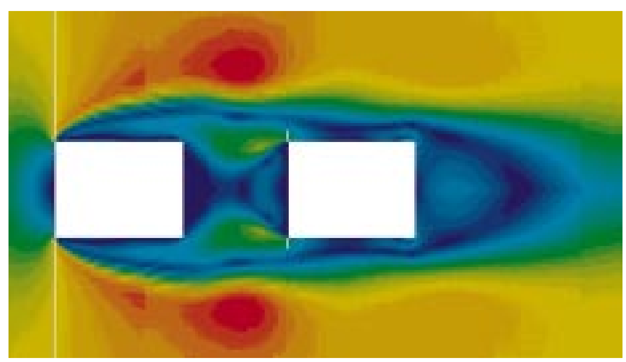


Fig. 8 - Mach contours showing separation of submunitions and collision avoidance, based on CFD simulation of design modifications

Elimination of Explosives and Propellants Through Environmentally Safe Open-Air Detonations

Environmentally safe disposal of unexploded conventional, chemical, and biological ordinance presents a substantial challenge worldwide. In addition to the over 800,000 tons awaiting disposal, over 11 million U.S. acres contain significant unexploded ordinance concentrations. Because of their age and composition, more than 60% of this demilitarized inventory is not amenable to disposal by means other than by open-air detonation or open-air burning. Human health and ecosystems concerns severely restrict and sometimes prohibit open-air detonation and burning. An ongoing joint Army, Navy, and Environmental Protection Agency effort has been established to develop ways to improve the environmental safety by the use of new open-air detonation and burning technologies. HPC resources and analyses contributed substantially to the design of a pilot-scale incinerator structure now being constructed at Dugway Proving Ground. Simulations were performed on over 20 proposed design options. The tests identified and resolved a number of problems for which no other practical means of analysis existed. Open-air detonation and burning designs developed by using this HPC-aided approach provide potential to allow the disposal of unexploded ordinance in an environmentally safe manner. Figure 9 is an example of a simulated open-air containment/detonation facility.

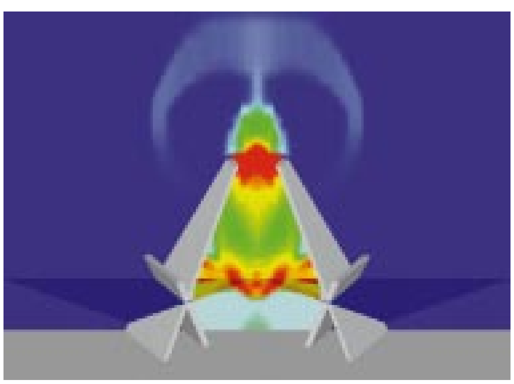


Fig. 9 - Potential octagon design of a containment facility for open-air detonation of expired and obsolete munitions

Conducting and Semiconducting Polymers by Design

The list of applications for organic materials that conduct electricity or modify the behavior of light is growing continuously. Sensor protection, electromagnetic shielding, lightweight batteries, fast optical communication, or replacements for metal wiring are some of the applications being considered by the DoD. However, in many cases, there are no known materials that can meet all of the requirements imposed on them by the various applications. Hence, new materials and materials concepts are needed to try to fill these voids. Computational chemistry plays an increasingly important role in the search for new optical and conducting materials. Accurate quantum chemical techniques are computationally intensive, and the computational resources required grow rapidly with the molecular size. A new, highly parallelized computer code for predicting molecular structures and properties that combines accurate *ab initio* quantum mechanical calculations with molecular dynamics simulations has been developed and is being tested on large molecules with promising conduction properties, such as shown in Fig. 10. Several massively parallel systems provided by the DoD HPC Modernization Program were used by the Air Force to develop the computational chemistry codes that are now being used to investigate the properties of new conducting and semiconducting polymers.

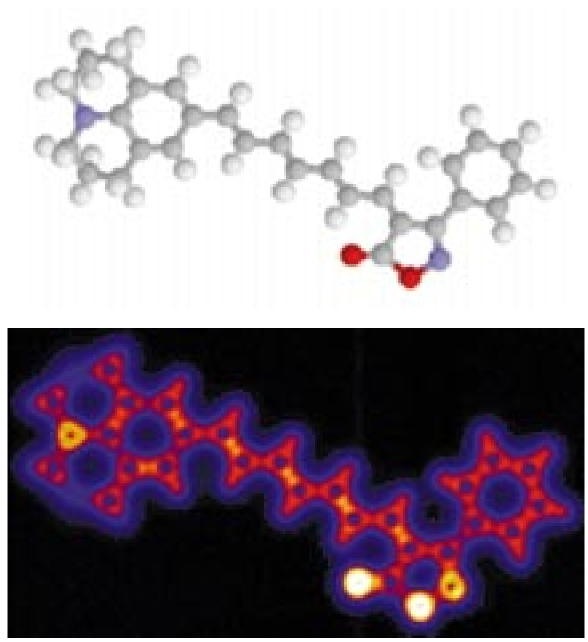


Fig. 10 - Structure and electron density of a push-pull polyene calculated by using PAIMD on the TMC CM-5

Determination of Blast Damage on Structures

Accurate blast damage assessments of large, complex structures have become a greater concern since the Gulf War. In contrast to testing large structures for blast resistance, which is very expensive, detailed HPC simulations offer a unique, accurate, and cost-effective approach to survivability assessment. To enable an accurate blast damage assessment, a fully integrated computational fluid dynamics and computational structural dynamics methodology was developed under the sponsorship of the Defense Special Weapons Agency. The integrated methodology enables the simultaneous determination of the following sequence of events: the detonation and fragmentation of a penetrating conventional warhead, the blast and fragment transport through the structure, the forces exerted on the structure by the impinging shocks and fragments, the deformation and motion of the structure, and the structure's failure modes. Figure 11 shows the application of this methodology to an explosion at the World Trade Center.

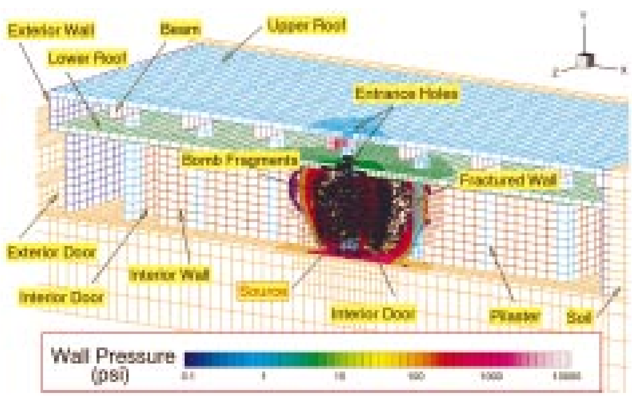


Fig. 11 - Three-dimensional MAZe CFSD simulation of a bomb detonation in a structure (air pressure contours on wall surface at 1 ms)

Advanced Warfighting Concepts Using Plasmas

It is accepted as fact that understanding the flow of air around an aircraft is vital to aircraft design and control. For similar reasons, understanding the behavior of an ionized gas, or plasma, in an environment that supports electric and magnetic fields is crucial to a variety of advanced warfighting concepts, including directed energy weapons based on microwave radiation and advanced hypersonic aircraft and missiles. Plasmas are subject to many instabilities that make control of their components particularly difficult. Until now, time-dependent numerical simulation of dense plasma phenomena in three spatial dimensions has been too coarse and too time consuming to be of great use. Only with the advent of effective algorithms that take advantage of a modern, distributed HPC environment were we able to simulate the complex physical phenomena that take place in a plasma, as shown in Fig. 12. The Air Force validated the computational and physical algorithms used in the numerical plasma simulation through experimental comparisons. Now the same simulation techniques are being used on a variety of advanced weapon concepts that require control over the plasma environment.

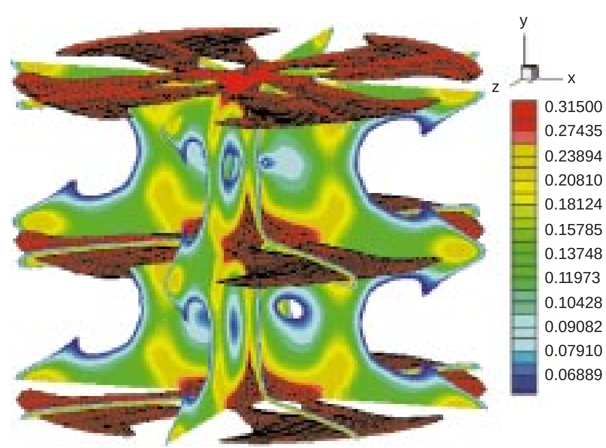


Fig. 12 - Cut planes and isosurfaces of mass density (in kg/m^3) of radially compressing plasma at 50 ns. The classical Rayleigh-Taylor spike and bubble pattern is easily recognized. The strong azimuthal variations are an indication of important 3-D physics.

Cofired Ceramic Package for a Ka-Band Microwave Monolithic Integrated Circuit Phase Shifter

Microwave monolithic integrated circuit components are an integral part of military sensors, detectors, and weapons systems. These components are encased in hermetic packages to reduce electromagnetic interference and minimize radiation leakage. A variety of packages based on cofired ceramic technology have been developed for use on high frequency applications. In order to integrate the microwave monolithic integrated circuit component, an accurate high-frequency characterization of the electromagnetic environment around the package is required. Until now, package modeling has been limited by the large size and complexity of the problem, thus leading to long design cycles, low yield, and high cost. For a single package, the frequency characterization task can require 40 hours of computation on conventional serial processors. Using a scalable parallel system, this task was reduced to 1 hour. Figure 13 is a diagram of a microwave monolithic integrated circuit package and a sample output of the model used. The greatly improved computational capability allows for better design optimization, thus leading to more effective materiel for the warfighter.

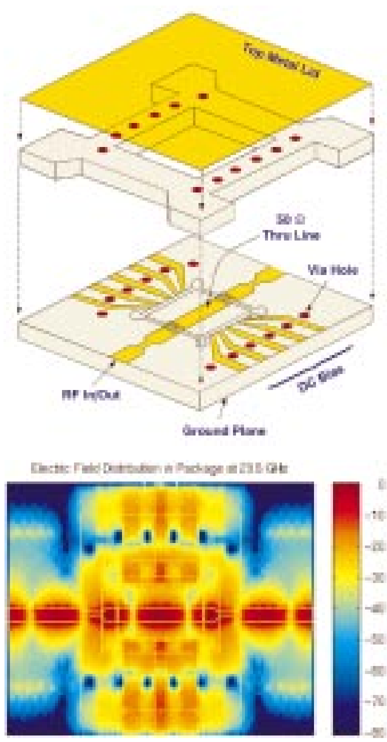


Fig. 13 - The 18-40 GHz MMIC package for phase shifter chip and electric field distribution in the package

Embedded HPC for Real-Time Target Detection and Tracking

Airborne surveillance platforms, proven effective during operation Desert Storm, are challenged to detect and track even smaller and slower targets both on the ground and in the air. New fiscal requirements further constrain researchers to increase the system flexibility and decrease the total system cost simultaneously . The military-unique “black boxes” currently used for the real-time radar signal processing are expensive and lack the flexibility to implement the latest generation of signal processing techniques. Leveraging commercial HPC technology provides an order of magnitude improvement in both system price and flexibility and also demonstrates a transition path from laboratory simulations to real-time implementation onboard aircraft. In this case, one of the latest techniques for detecting small targets from airborne radars, known as Space-Time Adaptive Processing, was implemented by the Air Force on a DoD HPC system and then ported to a smaller, ruggedized supercomputer that flew on a test aircraft. Figure 14 shows the result of Space-Time Adaptive Processing. The supercomputer met the challenge of processing 16 channels of radar data under real-time constraints and sustained 60% of its peak theoretical performance during the calculations. The flexibility of the embedded supercomputer allowed all the functions from raw data collection through target detections to be implemented instead of the traditional sequencing of “black boxes.”

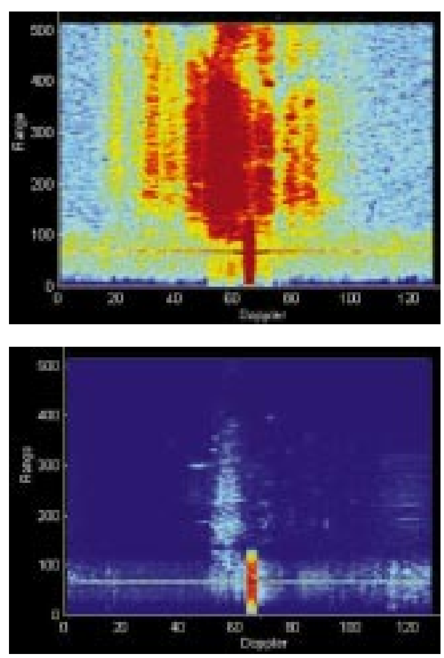


Fig. 14 - Clutter prior to and after Space-Time Adaptive Processing

Global Ocean Modeling

Global ocean modeling is a Grand Challenge problem, generally thought to require computational capabilities beyond the availability of current-generation HPC systems. By careful choice of computational methods, the Navy has been able to run a global ocean model on existing DoD HPC systems. The world's most sophisticated global ocean model was demonstrated by using multiple HPC resources. Figure 15 is a snapshot of sea surface height (comparable to satellite altimeter measurements) predicted by the model. An important milestone in the field of global ocean monitoring is the ability to run a full-scale global ocean model by producing a prediction system capable of providing detailed descriptions of ocean activity. This capability is important to military operations, including mine warfare in littoral (coastal) regions, antisubmarine warfare, search, and rescue. Commercial applications include ship routing, fishery forecasting, and global environmental monitoring, e.g., pollutant-spill risk assessments, El Niño forecasts, and global change studies.

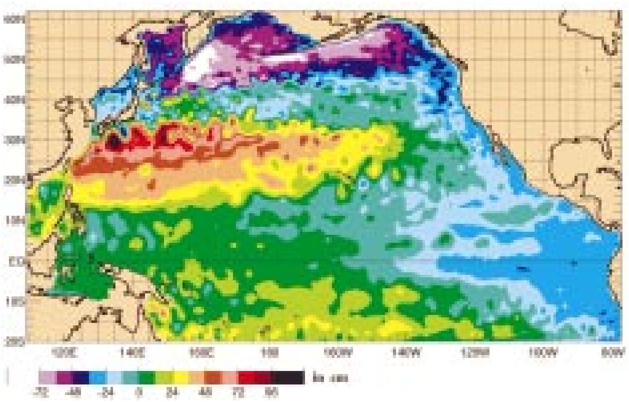


Fig. 15 - Sea surface height snapshot for 21 January 1986 simulated by a Pacific Ocean model with 1/16° resolution for each variable. Contour interval is 12 cm.

Pollutant Cleanup Strategies within DoD

The cleanup of contaminated groundwater resources are a prime concern at over 7,500 DoD sites. Environmental quality modeling and simulation technology, shown in Fig. 16 as executed on HPC resources, are keys to the timely evaluation, design, and operation of groundwater remediation systems that are both technically proficient and cost effective. By using environmental quality HPC technology, the best cleanup strategies are selected and, in turn, optimized for site-specific conditions prior to actual field implementation. Following field implementation, HPC technology provides the basis for refining or enhancing the operation of remediation technologies. As an example, use of such technology at a single DoD site (Schofield Barracks, Hawaii) resulted in the formulation of a cleanup strategy whose costs are less than estimated for a nonoptimized design. Perhaps even more important, regulatory acceptance of the modeling and simulation results from this installation were made possible and contributed directly to the acceptance of the more cost-effective cleanup strategy.

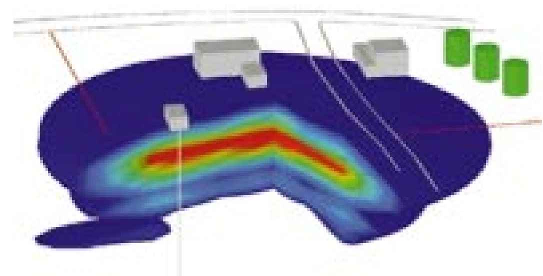


Fig. 16 - Desktop visualization of the DoD Groundwater Modeling System, showing a conceptualized contaminant plume (surface features and one observation well superimposed)

IMPLEMENTATION STRATEGY

The HPC Modernization Program is now entering the operational capability phase of an implementation continuum that was initially documented with the publication of the first HPC Modernization Plan in 1992 and updated in 1994.

During the first phase of the program, existing DoD laboratories were selected for placement of HPC resources, including a small number of experimental parallel systems. The Major Automated Information System Review Council approval is required for every major event throughout the program life and initiated the documentation that resulted in a $1.4 billion delegation of procurement authority from the General Services Administration.

During the second phase of the program, the program office established two interim major shared resource centers and the Interim Defense Research and Engineering Network. The program also obtained Major Automated Information System Review Council approval of acquisition milestone decisions and completed five major acquisitions—four to establish integration contractors for each of the four major shared resource centers and a telecommunications services contract to provide the Defense Research and Engineering Network. The HPC Modernization Office began an ongoing requirements collection and analysis effort to determine the immediate and long-term HPC requirements within the scope of the program. The results of the initial requirements analysis and the overall acquisition and implementation plans of the program were documented in the second HPC Modernization Plan, published in 1994. The major contract awards were consummated in calendar year 1996.

The third phase, documented in this plan, is focused on delivering the HPC infrastructure to DoD users. The focus in earlier phases was a combination of procurement of interim capabilities and planning and acquisition activities required to effect the 1996 contract awards. The focus today is on enabling the users to deliver computational science results to the warfighter. Therefore, the implementation is principally concerned with (1) the applications needed to support the warfighter mission, (2) the ongoing upgrade of HPC technology to support user capabilities, including both center facilities and network services; and (3) the management of the program to assure a continuing environment for innovation and leadership in the application of computational science to defense challenges.

Fiscal Year 1997 Planned Program

As a result of the completion of acquisition actions in fiscal year 1996, all four major shared resource centers have begun operations. By the end of calendar year 1997, all program elements will be operational, and network services will be operational across the user community. The specific program plans, by program initiative, are described below.

HPC Centers Initiative. The program will continue the modernization and sustainment of the HPC centers, as follows:

Distributed Centers - The program will assess and prioritize HPC requirements for distributed centers in fiscal years 1997 and 1998 and acquire and deploy new systems or upgrades to existing systems that were approved for implementation in fiscal year 1997, as part of the fiscal year 1997/ 1998 review process.

Major Shared Resource Centers - Additional HPC systems, storage, and scientific visualization capabilities will be acquired to populate and upgrade the established major shared resource centers to help meet the projected HPC requirements of the laboratories and research and development centers. Over a 2-year period (i.e., fiscal years 1997 and 1998), major shared resource center contract options will be exercised to upgrade performance at the major shared resource centers, minimally tripling the initial computing capability at each site. Fiscal year 1997 marks the first year of this 2-year effort.

Networking Initiative. During fiscal year 1997, the Defense Research Engineering Network's initial performance capability will become operational, providing 10 megabits per second to 155 megabits per second services to the user community in the first year. The initial performance capability, 10 existing nodes in the interim network, will be upgraded to 10 megabits per second or 155 megabits per second. Acceptance of the initial capability is scheduled for the 4th quarter of fiscal year 1997.

Software Support Initiative. Development efforts will continue in the software support initiatives. Each project will be reviewed in accordance with established performance metrics and project-specific milestones. The integrated modeling and test environment projects were initiated in the 2nd quarter of fiscal year 1997. All of the 43 initial CHSSI projects will be funded and fully under way during this fiscal year. At least one of the projects will enter formal alpha testing as specified in the CHSSI Test and Evaluation Master Plan. A workshop will be held in June 1997 for the project developers to review programming standards and performance metrics.

Fiscal Year 1998 Planned Program

During fiscal year 1998, the infrastructure will be fully operational. In addition to normal management and sustainment of the program, the HPC Modernization Program will continue to focus on enabling users to transition to scalable systems. Continued leverage of national HPC investments, particularly in software, will continue to be a priority of the program's management. The description of planned expenditures as documented in support to the President's budget includes the following.

HPC Centers Initiative. The program will continue the modernization and sustainment of the HPC centers, as follows:

Distributed Centers - The program will acquire and deploy new systems or upgrades to existing systems that were approved for fiscal year 1998 implementation. Proposals will be solicited from DoD services and agencies for fiscal year 1999 implementation.

Major Shared Resource Centers - The program will sustain the existing capability and continue the modernization process by acquiring additional HPC systems, storage, and scientific visualization capabilities; these are needed to populate and upgrade the established major shared resource centers to meet the projected HPC requirements of the laboratories and research and development centers. Over a 2-year period (i.e., fiscal years 1997 and 1998), major shared resource center contract options will be exercised to upgrade performance at the major shared resource centers, minimally tripling the initial computing capability at each site. Fiscal year 1998 marks the second year of this 2-year effort.

Networking Initiative. The primary service provided by the Defense Research Engineering Network contract will continue operations, providing 10 megabits to 622 megabits of services to the user community. Options to increase bandwidth at selected sites will be executed. Transition from the Interim Defense Research Engineering Network to Defense Research Engineering Network for all remaining sites is scheduled for completion by late fiscal year 1998.

Software Support Initiative. Development efforts in the software support initiative will continue, as will the projects approved for the integrated modeling and test environment computational technology area. The common HPC software support initiative will continue to develop shared scalable applications-supporting software to exploit scalable HPC assets. Projects will be reviewed in accordance with established performance metrics and project-specific milestones. During fiscal year 1998, approximately half of the CHSSI projects will enter the formal alpha testing phase. Depending on the outcome of this testing, many of these projects will then enter beta testing and early use by a broader but selected group of users. These users will not only help to evaluate the efficacy and scientific accuracy of the software but will also form the core team for technology transfer and dissemination to the broader community after successful completion of the test process.

Fiscal Year 1999 Planned Program

During fiscal year 1999, the HPC Modernization Program will continue to focus on user enablement via ongoing management of the core program initiatives. In addition, planning will begin for the acquisitions required to sustain the DoD HPC infrastructure beyond fiscal year 2001. This planning cycle will also involve a reassessment of long-term requirements and various implementation options that might uniquely meet the needs of the DoD through the 2010 time frame. The description of planned expenditures as documented in support to the President's budget includes the following.

HPC Centers Initiative. The program will continue the modernization and sustainment of the HPC centers, as follows:

Distributed Centers - The HPC Modernization Program will again assess and prioritize HPC requirements for distributed centers and will acquire and deploy new systems or upgrades to existing systems via service-sponsored white paper proposals to accomplish mission needs.

Major Shared Resource Centers - The program will sustain the existing capability and continue the modernization process by acquiring additional HPC systems, storage, and scientific visualization capabilities; these are needed to populate and upgrade the established major shared resource centers to meet the projected HPC requirements of the laboratories and research and development centers. Over the 2-year period (i.e., fiscal years 1999 and 2000), major shared resource center contract options will be exercised to upgrade performance at the major shared resource centers, minimally tripling the capability at each site over the previous performance level. Fiscal year 1999 marks the first year of this 2-year effort.

Networking Initiative. Network connectivity will be sustained for HPC Modernization Program users. Options to increase bandwidth at selected sites will be executed to meet the increased demands resulting from upgraded computing capabilities at the HPC centers. Additional sites will be added to the Defense Research Engineering Network.

Software Support Initiative. Development efforts in the software support initiative will continue. The common HPC software support initiative will continue, developing shared scalable applications-supporting software to exploit scalable HPC assets. Projects will be reviewed in accordance with established performance metrics and project specific milestones. By the end of fiscal year 1999, we anticipate being able to begin testing for those projects not ready for alpha testing in the previous year and complete testing and formal release for broader use for the projects that entered alpha testing in fiscal year 1998. By this time we also anticipate being able to measure the impact of the earliest codes on both user capability and on efficiency of use of program resources.

Funding

The current program is projected to spend $1310.7 million for fiscal years 1998 through 2003. Table 13 shows the funding profile by year and major spending category for fiscal years 1996 through 1997, including actual budgets for fiscal years 1996 and 1997 and 5-year projections from the President's fiscal year 1998 budget. This program funding represents a reduction of approximately $500 million from the budget profile shown in the 1994 HPC Modernization Plan, assuming level funding projections for the fiscal years 2000 through 2003. While there have been a number of budget adjustments since the publication of the 1994 HPC Modernization Plan, most of the difference resulted from a single $269 million reduction sustained by the program as part of the final resolution of the Defense Program Objective Memorandum (POM) for fiscal years 1997 through 2001.

Comparison of the current budget profiles with earlier program budget projections presented in the 1994 plan, industry briefings, and acquisition documents indicates that most of the major reductions referenced above—approximately $100 million per year beginning in fiscal year 2000—will be sustained by the HPC Modernization Program system acquisition account. While the lower budget is sufficient to exercise the base capability as currently programmed for Performance Level 3 of the Major Shared Resource Center contracts, this capability will likely address less than 30% of the projected validated computing requirements for years 2000 and beyond. As part of its strategic planning efforts, the HPC Modernization Program staff is examining options to assure that the highest priority warfighter needs are met in light of these shortfalls.

The networking budget will increase to level approximately twice that budgeted for fiscal year

Table 13 - Funding Profile ($M)

	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03
System Acquisitions	129.3	124.0	91.9	84.5	67.0	43.6	54.9	54.2
Networking	17.8	18.0	26.9	35.7	37.8	39.6	38.0	39.4
System Applications Support	9.6	20.7	22.7	23.7	24.4	25.6	24.6	25.5
Sustainment and Operations	56.3	84.2	76.6	89.4	93.7	98.6	94.6	97.9
Total	**213.0**	**246.9**	**218.1**	**233.3**	**222.9**	**207.4**	**211.9**	**217.0**

1997. While the DoD will realize substantial economic savings for comparable service in the transition from the Interim Defense Research and Engineering Network to the Defense Research and Engineering Network, the demand for high performance networking will increase to reflect the dramatic increase in both shared resource capability and HPC requirements across the user base. Another important factor in this growth will be the increased importance of remote collaboration across functional and service boundaries, and with the broader research and development enterprises in academia and industry. HPC-based collaborative methods—important to cost-effective development of optimized warfighter technologies for the future—will require the transmission of extremely large image visualization objects, often in real time or near real time.

The continued strong funding in the software support initiative and in the sustainment and operations budget lines reflects the importance that the HPC Modernization Program places on software, integration, and related shared services to the users of HPC throughout DoD. The sustainment budget, for example, includes the highly leveraged investments in training and collaboration with the academic community via the Programming Environment and Training elements of the program. These investments will continue to guarantee that the focus of the program remains on enabling users to address warfighter needs, not only by strengthening the support infrastructure, but also by providing effective mechanisms for continued leverage of both national and industrial investments in HPC-based productivity.

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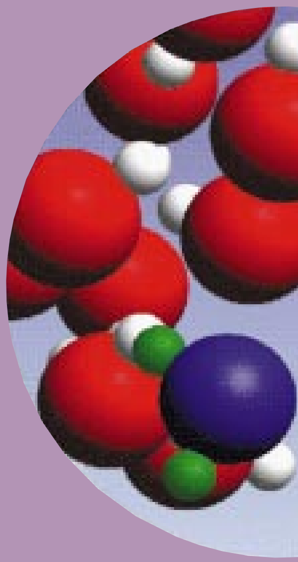

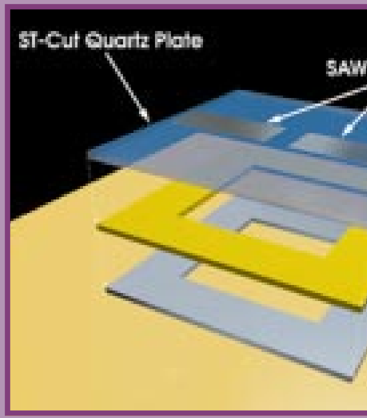

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